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Vegetable and Small Fruit Growing in Toxic Ex-Orchard Soils of Central Washington

by
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The Washington variety of red raspberries grow well in arsenic toxic soils of central Washington

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Vegetable and Small Fruit Growing in Toxic Ex-Orchard Soils of Central Washington [1]

C. L. Vincent

The tree fruit industry of the Wenatchee-Okanogan district and of the entire Pacific Northwest is passing through a period of readjustment. This is not the first important readjustment that has occurred in the fruit industry of Washington. The number of producing apple trees reached its peak about 1919, and has declined for each census period since that time. Reduction has taken place in Chelan and to some extent in Okanogan and Yakima Counties.

Removal of apple trees has been heavy in some areas since 1934, and occurred at accelerated rates from 1937 to 1940. In some instances pulling was done to thin orchards of excess trees, to change varieties or species, to aid in the control of insects and diseases, to remove unprofitable varieties, or to reduce the acreage of land unsuited for apple production. Tree removal has taken place to the extent that today some 12,000 to 15,000 acres of ex-orchard lands are lying idle. Some of this land is suitable for replanting, but much of it probably should not be replanted to fruit trees.

The particular problem involved in a successful rehabilitation of these lands is to rid the soils of certain toxic residues, accumulations from the sprays applied to apple trees before their removal. During the years that these acreages were in orchard, heavy spray applications were made each year to control codling moth. Lead arsenate is the principal spray material used and because of the heavy spray program, an arsenic soil-complex developed to such an extent that it was nearly impossible to grow most crops in these soils after removing the trees. This resulted from a build-up of sufficient parts per million of water soluble arsenic in the soil to become toxic to the growth of most crops.

OUTLINE OF EXPERIMENT

In 1939 the Division of Horticulture of the Washington Experiment Station began the study of the handling of arsenic-toxic orchard soils to determine which horticultural crops, if any, would grow on them. Three plots, each one-half acre in size, were established in the Wenatchee area in the spring of 1939 for the purpose of studying the effects of arsenic toxicity on the growth and development of certain vegetable and small fruit crops. The plots were selected (a) on the basis of interval after apple trees were removed; (b) on soil texture;

[1] Work conducted in cooperation with the Extension Service in Chelan and Douglas Counties; also with the Smith-Hughes instructor, Jesse Helm, Wenatchee High School.

and (c) on the arsenic content of the soil. The trees on each plot were from 30 to 40 years old when removed. One plot on a heavy clay loam soil, had been out of orchard for six years prior to 1939. A second plot, on a medium, gravelly loam soil, had been out of old apple trees for two years prior to 1939. The third plot, on an Ephrata fine sandy loam soil, had been out of orchard only one month prior to planting in 1939. No plantings had been made on these plots following tree removal. There was, however, some weed growth on the plot longest out of orchard.

Each plot was divided into four equal areas and the soil handled as follows: (a) ammonium phosphate was applied at the rate of 48 pounds of actual nitrogen and 60 pounds of phosphoric acid per acre; (b) cow manure was applied at the rate of 16 tons per acre; (c) cow manure applied at the rate of 16 tons per acre, and 50 pounds per acre of actual nitrogen, in the form of ammonium sulphate, was broadcast previous to plowing under the manure; (d) 50 pounds of actual nitrogen per acre was broadcast in the form of ammonium sulphate.

In the spring of 1939, areas (a) and (b) were planted to crops as follows: asparagus, corn, tomatoes, pole beans, Lima beans, peas, onions, potatoes, grapes, raspberries, dewberries and strawberries. Other vegetable crops were included in the plantings from year to year. The same year areas (c) and (d) were each planted with a mixture of spring rye and Markton oats, sown at the rate of 40 pounds and 60 pounds per acre respectively. The oats were not tolerant of arsenic toxicity and died soon after germinating. After the rye reached the bloom stage, 50 pounds of actual nitrogen per acre, was broadcast to the rye, and this plowed under. The nitrogen was added primarily to aid in the rapid decomposition of the rye organic matter.

In mid-August 1939, areas (c) and (d) were planted to Rosen rye and the crop allowed to grow until March 1940 when it was plowed under and the areas planted to vegetable and small fruit crops comparable to those planted in sections (a) and (b). Thereafter areas (c) and (d) each September were planted to Rosen rye at the rate of 80 to 100 pounds of seed per acre and the growth plowed under the following spring before planting to vegetable crops.

Soil analysis. At the beginning of the study a soil analysis was made by the Bromide method of the arsenic content of each plot. The plot just out of 40-year old apple trees was shown to contain, on an average, 33 parts per million of water soluble arsenic in the upper six inches of soil. The second plot that had been out of old apple trees two years contained 22 parts per million of water soluble arsenic and the third plot, having heavy soil, that had been out of old apple trees for six years, averaged 8.5 parts per million of water soluble arsenic. In the experiments outlined, certain soil handling practices were de-

veloped to determine if the arsenic content in ex-orchard soils could be reduced to a point where commercially important vegetable and small fruit crops could be grown successfully. A study of plant varietal resistance to water soluble arsenic was also undertaken.

In a previous study of unproductive ex-orchard soils in Yakima County by Vandecaveye, Horner and Keaton (5), it was found that soil samples taken from the surface six inches of a number of unproductive soils contained from 4.5 to 12.5 parts per million of readily soluble arsenic. The poor growth of young alfalfa and barley in the affected fields seemed to be roughly in proportion to the concentration of readily soluble arsenic in the surface soil. When samples of soil, free from accumulations of readily soluble arsenic, were treated with five parts per million or more of water soluble arsenic and planted to barley, toxic symptoms developed in the young plants identical with those observed on barley growing in affected fields in Yakima County of Washington.

TOXIC SOIL TREATMENTS

There are many variable factors such as arsenic toxicity, soil classes and soil fertility, organic matter, and climatic conditions that complicate the handling of ex-orcharrd soils. Investigations by Vincent (7), and by Vincent, Morris, and Overholser (8) have shown that by following certain soil building and crop rotation practices that the arsenic content of medium-heavy and heavy soils can be reduced to a place where crop response is almost normal. They found rye to be very tolerant to arsenic when the seed was planted in arsenic toxic soils, and that rye made good plant growth in soils rather low in organic matter but high in water soluble arsenic. (Figure 1.)

Some vegetable and small fruit crops were injured or unable to grow when planted in toxic-orchard soils, immediately after removal of the old apple trees, especially those of light sandy texture, unless at least two or more crops of rye were grown and plowed under before planting to vegetables and small fruits. This agrees with the findings of Crafts and Rosenfels (2) who report that arsenic toxicity following applications of arsenic compounds is relatively high in sandy soils and relatively low in clay soils. They also indicate that arsenic toxicity in soils can be accounted for, largely in terms of fixation, and that fixation is higher in heavy soils than in light soils, hence, a given amount is less likely to be toxic to plants in heavy soils than in light soils.

TREATMENTS WITH AMMONIUM PHOSPHATE
(Section A)

One section in each of the three plots was treated annually, just previous to plowing, with ammonium phosphate (16-20), broadcast at

Fig. 1. Rye grows well on ex-orchard land heavily impregnated with water soluble arsenic.

the rate of 48 pounds of available nitrogen and 60 pounds of available phosphorus per acre. (See Chart 1.) Several kinds of vegetables and small fruits were planted in these sections in the spring of 1939 and vegetables were planted each succeeding year through 1943.

Vegetables planted in the section treated with ammonium phosphate, in the plot with heavy soil longest out of orchard and lowest in water soluble arsenic from the beginning, were inferior in growth developments to the same kinds planted in the other sections of the plot under different soil treatments. The plants in this section in all plots were smaller and the leaves a more yellowish-green color during the first three seasons than was the case in the other sections of the plot. The exceptions were potatoes, asparagus and tomatoes, which kinds made growth comparable to the same varieties in the other sections.

Yields with all other vegetables that grew to maturity were lower in this section during the period of the study than was the case with plants grown in the other sections of the plot with different treatments.

In the plot out of orchard two years, and the plot out of orchard one month, respectively, prior to planting, where the soil in each case is of a lighter texture, most vegetables did not grow beyond the seedling stages in the ammonium phosphate treated sections. Potatoes, asparagus and tomatoes were the exceptions, for they grew almost as well from the first year in the lighter soils heavily impregnated with arsenic as did these crops planted in the heavier soil lower in water soluble arsenic.

Chart 1. A diagram showing how each of the three toxic plots was laid out and the treatment each section received.

SECTION (a) ⅛ acre	SECTION (b) ⅛ acre	SECTION (c) ⅛ acre	SECTION (d) ⅛ acre
Treatment: Ammonium phosphate	Treatment: Cow manure	Treatment: Cow manure, rye, and nitrogen	Treatment: Rye and nitrogen
Method: Apply ammonium phosphate (16-20-0) yearly at the rate of 48 lbs. actual N. and 60 lbs. P_2O_5 per acre. Plant to vegetables and small fruits in 1939 and plant vegetables yearly thereafter.	Method: Make yearly applications of cow manure at rate of 16 tons per acre. Plant to vegetables and small fruits in 1939 and plant vegetables yearly thereafter.	Method: 1. Apply manure yearly as in Section (b). 2. Plant to Rosen rye yearly each fall. 3. Add ammonium sulphate at the rate of 50 lbs. actual N. per acre before plowing under each rye crop. Plant spring rye in spring 1939. Turn under in heading stage. Before plowing under rye add N. as above. In Sept. of 1939 and each succeeding year plant Rosen rye. Turn under in the spring adding N. as above. Plant to vegetables and small fruits in spring 1940 as in Sections (a) and (b) and vegetables yearly thereafter.	Method: Handle this section as Section (c) except cow manure is omitted.

Vegetables planted in the sections treated yearly with ammonium phosphate responded somewhat better after four years of treatment, when compared with the first year, in that the green color of the leaves and plant stand was greatly increased in all cases, even with potatoes.

The growth of small fruits in the section treated with ammonium phosphate was excellent, particularly in the less toxic heavy soil plot, although some varieties were more tolerant to arsenic toxicity than other varieties of a kind. Grape growth, measured in terms of cane length and general plant vigor, was better in this section than was the case with the same varieties planted in the manure sections. Likewise, grape growth in the various sections treated with ammonium phosphate was comparable with the grapes in the green-manured areas which were planted to grapes in the spring of 1940, after two crops of rye had been grown and plowed under. Strawberries grew normally in heavy soil treated with ammonium phosphate, but failed to grow in the more toxic sandy soil just out of old apple trees. In the medium-heavy soil plot out of orchard two years previous to planting, some strawberry varieties, especially the Fairfax variety, grew better than others.

Soil texture greatly influenced plant development and yields of both vegetables and small fruits. In every case plant response was superior when the vegetables and small fruits were planted in heavy soils than in lighter ones.

According to Crafts (1), raising the nutrient level in the soil by increasing the supply of available nitrates did not reduce arsenic toxicity. This work shows that treating the soil with ammonium phosphate did reduce the parts per million of water soluble arsenic considerably as shown in Table I. It was not, however, reduced sufficiently so that all crops grew equally well, even following five years of treatment.

The analysis for 1939 shows the parts per million of water soluble arsenic present in the soil following the laying out of the plots into sections, but before the treatments were started. The data for 1941 were obtained following three soil treatments and three growing seasons. Just why the reduction of water soluble arsenic, where ammonium phosphate was applied, was greater in the case of the lighter soils than in the heavy soil plot is unknown unless it is from the leaching effects of the irrigation water. According to Morris, Overley, and Rogers (4), the toxic condition of orchard soils was not greatly reduced by the application of commonly used commercial fertilizers when applied alone as measured by plant growth.

Work by the Division of Soils of the Washington Agricultural Experiment Station (unpublished) shows that with barley and alfalfa available phosphate fertilizers may antagonize the toxic action of arsenic when the latter is not exceedingly high and the native supply of phosphorus is low. With soils exceedingly high in soluble arsenic, diluting the toxic surface with non-toxic subsoil, the concentration of arsenic may be reduced to a value that can be antagonized by super-

Table 1. Soil Analysis of the Sections of the Three Plots Showing Parts Per Million of Water Soluble Arsenic

Plot	Treatments given to the plots and Micrograms of arsenic Trioxide or Water Soluble Arsenic			
	Ammonium phosphate	Cow manure	Rye, cow manure and ammonium sulphate	Rye and ammonium sulpnate
	ppm	ppm	ppm	ppm
Plot out of orchard six years. Heavy clay soil				
1939	9.0	8.7	9.3	7.3
1941	7.0	0.5	0.5	0.8
1943	1.9	2.2	1.3	1.6
Plot out of orchard two years. Medium gravelly loam soil				
1939	25.3	21.4	23.2	18.5
1941	9.6	16.8	3.0	7.0
1943	4.6	5.3	5.0	2.8
Plot out of orchard one month. Fine sandy loam soil				
1939	34.2	35.0	33.5	30.5
1941	9.0	13.0	28.2	21.0
1943	11.7	11.6	16.9	6.3

phosphate. It is possible that continued applications of ammonium phosphate may in time reduce the toxic properties to a point where most vegetable and small fruit kinds will grow and produce normal crops.

TREATMENTS WITH MANURE (Section b).

A second section in each of the plots received yearly applications of cow manure at the rate of 16 tons per acre. (See chart 1.) The manure was broadcast during late winter and early spring and was plowed under approximately two weeks before the area was planted to crops comparable to those planted in section (a) of each plot.

The growth of all arsenic tolerant vegetable crops, Table 2, in the various sections treated with manure, was very little better than those in the sections treated with ammonium phosphate until after the third application of manure was made in 1941. During the growing season of 1941, all of the vegetables planted in the manured section of the plot longest out of orchard (heavy soil) grew almost normally. However, in this section of the medium heavy and sandy soil plots there was little, if any, improvement in plant response over previous crops except in the case of tolerant vegetables like potatoes, asparagus, toma-

toes, and carrots, which grew well from the first planting made in 1939. Arsenic sensitive vegetables, Table 2, planted in the plots containing soils of lighter texture grew no better during 1942 than the same vegetables planted the first two years. This was because of the high arsenic content of the soil even though greatly reduced by treatment.

Manure applications reduced the water soluble arsenic content in the various sections of the three plots. (Table 1.) In the plot longest out of orchard, the amount of soluble arsenic was almost negligible at the end of the third growing season, being reduced from 8.7 to 0.5 parts per million of water soluble arsenic. The water soluble arsenic was likewise reduced by manure applications in this section of the plot out of orchard one month before planting to crops but to a much lesser extent in the plot two years out of orchard. However, in neither case was the water soluble arsenic reduced to a point where it was non-toxic to plants sensitive to arsenic.

The study shows that no great benefits were obtained by the plants from applications of cow manure in the least toxic plot until 18 to 24 months after application, or until a state of advanced decomposition had developed and the organic material had become a part of the soil. It is possible that the micro-organisms carried in the manure are affected by arsenic in the soil, greatly impeding the process of decay, and thus causing a nitrogen deficiency in the soil, which effects plant growth. Green and Kestell (3) reported that differences in the toleration of different species of bacteria for arsenic are very marked. Many that are very tolerant of arsenates are relatively sensitive to arsenite. About 10 per cent of the bacterial count of fresh stable manure was moderately tolerant and about one per cent was highly tolerant. Yeasts and molds generally showed a high degree of tolerance to arsenic.

Small fruits, except strawberries, grew well in the manured section of the three plots from the beginning, possibly because their roots were planted below the more toxic surface soil. Grape cane growth was good in the manured sections but was not quite equal to the cane growth in the sections treated with ammonium phosphate. Strawberries planted in the manured sections of the heavy and medium heavy soil plots responded somewhat differently. In the heavy soil all varieties planted grew normally. In the medium heavy soil strawberries grew fairly well but exhibited varietal differences. The Fairfax variety grew very well followed in turn by Red Heart and Premier. The Dorsett variety failed to survive transplanting. On the plot just out of orchard (very light soil type) none of the four strawberry varieties planted survived transplanting in the field.

TREATMENTS WITH RYE AS A GREEN MANURE CROP TO WHICH COW MANURE AND NITROGEN WERE ADDED (Section c.).

A third section (c), Chart 1, in each plot received an application of cow manure at the rate of 16 tons per acre and in addition ammonium sulphate at the rate of 50 pounds of available nitrogen per acre. This was applied in the early spring of 1939 and plowed under three weeks in advance of planting to a mixture of rye and Markton oats. After the rye reached the early bloom stage (the oats died while in the seedling stage), a second application of ammonium sulphate was applied at the rate of 50 pounds of available nitrogen per acre. The rye was then plowed under and allowed to decompose until late August. At that time the soil was thoroughly prepared and planted to Rosen rye.

In March 1940, the Rosen rye was plowed under and allowed to decay. Vegetables and small fruits of like kinds and varieties were planted in this section of each of the three plots, as planted in sections (a) and (b) in 1939. Since 1940, a fall crop of Rosen rye was seeded each year and allowed to grow until the following spring, when the crop was plowed under as green-manure. Before plowing, nitrogen was applied each year at the rate of 50 pounds of actual nitrogen per acre to aid in the decomposition of the organic matter.

The physical condition of the soil in these sections of the plots was markedly improved by the incorporation of the manure and rye organic matter, especially the heavy soil in the plot longest out of orchard. The lateral spread of water in the soil was greatly increased.

All arsenic-tolerant vegetables (Table 2) planted in 1940 in the rye-manure-nitrogen section of the plot having heavy soil made slightly better growth and the leaves of all plants were somewhat larger and much greener in color than the same vegetables planted in sections (a) and (b) of the plot. Likewise, the arsenic-sensitive sweet corn plants grew almost normally in 1940 in this section and produced an average of 1½ ears per stalk, compared to less than one ear per stalk on the average, for corn, in the ammonium phosphate and manured sections. The corn plants lacked uniformity, being somewhat shorter in those spots where old apple trees stood previously than in the tree interspaces. By 1942 the growth of sweet corn was normal in this secttion. In fact, during the 1942 growing season, all of the vegetables planted in the rye-manure-nitrogen section of the plot having heavy soil were making the best plant development and yielding better than like varieties planted in sections (a), (b) and (d) of the plot. Snap beans and garden peas, which are very sensitive to water soluble arsenic, grew fairly well in 1940 in the two rye sections and the plants were almost normal in 1941 in the rye-manure-nitrogen and in the rye-nitrogen

treated sections of the heavy soil plots in comparison with like varieties grown in non-toxic soils.

In the plots having medium heavy and sandy soil, arsenic resistant crops like potatoes, asparagus, tomatoes, and carrots, were somewhat more vigorous than like crops planted in sections (a), (b) and (d) of the plots. In the medium heavy soil plot, sweet corn made a better plant growth in this section in 1940 than in the other three sections, but the plants still lacked vigor and uniformity of stand as late as 1943. Peas planted from 1940 to 1942, inclusive, in the medium heavy soil plot, germinated well each year and grew to a height of six to eight inches, when the leaves turned yellow and the plants died without fruiting. In 1943 the vines grew somewhat taller and produced a few pounds of pods. During the same period, beans did not live through the seedling stage.

In the plot containing sandy soil, sweet corn, peas, and beans did not live through the seedling stages in any year, including 1943 except for a few scattering stalks of corn.

The four kinds of small fruits, namely: red raspberries, grapes, Boysenberries, and strawberries, planted in 1940 in the rye-manure-nitrogen section of the plot containing heavy soil made the best growth of all four sections, except in the case of grapes. Grapes were slightly better in the section treated with ammonium phosphate. This condition continued through the 1943 season.

In the medium heavy soil plot, the growth of all small fruit plants in the rye-manure-nitrogen section was intermediate between the same kinds and varieties grown in the heavy soil plot out of orchard six years before being planted, and those grown in the sandy soil plot out of orchard one month before planting. However, growth of small fruits was satisfactory except with strawberries and here a pronounced varietal behavior was exhibited. The variety Fairfax was distinctly more tolerant of arsenic and Dorsett the least so of the four varieties grown.

In the sandy soil plot, out of orchard one month prior to planting and the most toxic of the three plots, the growth of grapes, raspberries, and Boysenberries was rather slow during the 1940 season. In fact, the plants did not make rapid growth until 1942. In 1943 cane growth was very vigorous. Of the four sections of this plot, grapes, raspberries, and Boysenberries made the poorest growth in the rye-manure-nitrogen and the rye-nitrogen sections. This was probably because of the poorer stands of rye obtained each year due to the difficulty in obtaining sufficient water for this plot in late September.

Varietal behavior was rather pronounced in raspberries in this as well as in the other two plots, the Washington variety being much more tolerant of arsenic than Cuthbert, Tahoma, or Lloyd George—the other varieties planted. Strawberries failed to survive transplant-

ing each year in the sandy soil plot probably because the roots were of necessity planted in the more arsenic-toxic surface soil. Both fall and spring plantings of strawberries were made in this plot with like results.

TREATMENTS WITH RYE AS A GREEN MANURE CROP TO WHICH NITROGEN WAS ADDED (Section d).

A fourth section (d) of each of the three plots, Chart 1, was treated and handled in a manner similar to section three (c), except that no manure was applied.

The growth response of all vegetables and small fruits in this section of all three plots was similar to the same varieties planted in section (c) of the plots during the years 1940 and 1941. In 1942 and 1943, all kinds of vegetables and small fruits that were able to withstand the arsenic-toxic soil condition made decidedly better growth in section (c) than in section (d). This was evidenced mainly by a greater plant height and plant vigor, and also by a darker green color of the foliage. Yields in section (c) were slightly greater than in section (d). This probably resulted from an accumulative effect of the manure added each year, which probably aided in a tie-up of the water soluble arsenic to a greater extent than when rye and nitrogen were used alone.

The arsenic-sensitive plants, especially when planted in the light, sandy soil plot, reacted similarly in sections (c) and (d) throughout the entire period of the study. In fact, the growth of such plants in 1943 was little, if any, better than those seeded in 1940.

TOLERANCE OF CERTAIN VEGETABLES AND SMALL FRUITS TO ARSENIC

Investigations in the Wenatchee district have shown that asparagus, potatoes, tomatoes, carrots, tobacco, dewberries, grapes, and red raspberries will grow successfully in soils from which old heavily-sprayed apple trees have just been removed when the soils may contain as high as 33 parts per million of water soluble arsenic (Table 2). A decided improvement in plant growth and yield was obtained, in most cases, when a good stand of rye was grown and plowed under as green-manure.

The grouping given in Table 2 indicates the relative tolerance of crops to water soluble arsenic and the degree of success that might be expected when good cultural practices are followed. The tolerant kinds listed grew well on all three soil types included in the test regardless of the arsenic toxicity. In the case of strawberries, however, good growth was obtained only on the heavy and medium-heavy soils. On heavy soils containing nine or less parts per million of water soluble arsenic, the varieties of strawberries, Red Heart, Fairfax, Dorsett, and Premier grew equally well, while in medium heavy soils containing 25

Table 2. Classification of Vegetables and Small Fruits According to their Tolerance of Water Soluble Arsenic for Satisfactory Growth

Very tolerant	Fairly tolerant	Low or no tolerance
Asparagus	Sweet corn (on heavy and medium heavy soils)	Snap beans
Potatoes, Irish		Lima beans
Tomatoes		Onions
Carrots	Beets	Peas
Tobacco	Squash	Cucumbers
Dewberry	Strawberries (on heavy and medium-heavy soils)	Sweet corn (on light, sandy soils)
Grape		Strawberries (on light, sandy soils)
Raspberry, Red		

or less parts per million of soluble arsenic only the Fairfax variety grew normally. In light soils containing 30 to 33 parts per million of soluble arsenic, none of the four strawberry varieties grew even as late as 1943.

Asparagus. Asparagus is very tolerant of arsenic toxicity and is found growing "wild" in many orchards of irrigated central Washington, notwithstanding soil toxicity. In the experimental plot plantings, one-year-old roots of the Mary Washington variety were planted according to recommended practices.

Notwithstanding soil type and parts per million of water soluble arsenic, asparagus was one of the most reliable vegetables to grow and good crops of spears were harvested from each of the plots during each cutting year.

Potatoes. Certified seed of the Irish Cobbler and Bliss Triumph varieties of potatoes were planted each year in the various plots. Plant growth and yields have been good from the first year of planting. From yields obtained (Table 3), potatoes were the most promising crop to grow on toxic soils. Potato plant growth and yields, compared with growth and yields of potatoes grown under irrigated conditions in the potato sections of the State of Washington, were normal from the first planting. (Figure 2.)

The data (Table 3) show that yields increased with treatment up to 1943 when the potatoes in all plots were mildly affected with leaf curl disease.

Yields in 1940 in sections (c) and (d) after two rye green-manure crops were grown and plowed under were considerably increased above sections (a) and (b) planted in 1939 immediately after establishing the plots.

Following five years of investigations with potatoes grown in toxic soils it is evident that the best yields were obtained in those sections treated yearly (1) with 16 tons of cow manure per acre as a fertilizer

Table 3. Yields Per Acre of Bliss Triumph and Irish Cobbler Potatoes as Grown on Toxic Soils*

Treatment		Yield of potatoes planted in toxic soil out of orchard 6 yrs. before being planted (Heavy soil)		Yield of potatoes planted in toxic soil out of orchard 2 yrs. before being planted (Med.-heavy soil)		Yield of potatoes planted in toxic soil out of orchard 1 month before being planted (Sandy soil)	
		Bliss Triumph	Irish Cobbler	Bliss Triumph	Irish Cobbler	Bliss Triumph	Irish Cobbler
Ammonium phosphate		Tons	Tons	Tons	Tons	Tons	Tons
	1939	9.8	8.9	9.8	7.1	10.0	8.1
	1940	10.9	9.8	11.9	10.7	11.1	10.5
	1941	------	------	14.6	12.2	15.6	12.6
	1942	17.4	15.1	10.7	8.9	17.6	15.1
	1943	13.1	------	12.6	11.7	15.7	11.9
Average		12.9	11.4	12.0	10.3	14.6	11.8
Cow manure							
	1939	7.5	7.9	7.5	6.3	9.4	9.0
	1940	8.5	9.3	13.7	9.7	12.8	13.5
	1941	------	------	19.9	13.0	18.6	13.1
	1942	17.8	17.4	16.7	15.2	19.1	17.9
	1943	14.3	------	17.2	15.7	15.8	14.2
Average		12.2	11.7	15.2	12.0	15.3	13.7
Cow manure + rye + N.							
	1939	Planted to rye	Planted to rye	Planted to rye	Planted to rye	Planted to rye	Planted to rye
	1940	12.1	10.0	16.2	11.3	13.5	11.8
	1941	------	------	16.5	13.4	14.2	14.6
	1942	15.3	12.7	16 8	15.0	19.4	15.5
	1943	15.0	------	16.7	15.1	14.2	12.2
Average		14.3	11.5	16.7	13.8	15.5	13.7
Rye + N.							
	1939	Planted to rye	Planted to rye	Planted to rye	Planted to rye	Planted to rye	Planted to rye
	1940	9.7	11.0	12.6	11.3	13.2	10.1
	1941	------	------	17.8	12.5	14.7	10.5
	1942	14.0	12.6	14.8	12.1	14.6	10.2
	1943	13.2	------	14.5	13.3	16.7	11.3
Average		12.4	11.9	15.0	12.4	14.9	10.5

* No yield records were taken on either potato variety in 1941, on the plot out of orchard 6 years before being planted in 1939, through a misunderstanding with the caretaker. Likewise yield records were not obtained for the Irish Cobbler variety in 1943 in the same plot because of poor location of the planting.

and (2) with the rye-cow manure-nitrogen treatment. The greatest increases in yields, in the section treated with cow manure alone, were not obtained until 1941 after the previous manure applications had become well decomposed and had become incorporated as a part of the soil.

Fig. 2. Normal plant growth and yields are obtained when potatoes are planted directly in soil from which heavily sprayed apple trees have been removed.

Tomatoes. This is another crop that grew exceptionally well on all three plots notwithstanding soil texture or parts per million of water soluble arsenic. Because of the susceptibility of transplanted tomatoes to the curly top disease, the direct-seeding method was more suitable than the old transplanting method. From these studies, tomatoes planted by direct-seeding had less than two per cent of the plants affected by curly top whereas those transplanted had as high as 50 per cent affected with the disease.

In the direct seeding method, the seed was sown in rows four feet apart as soon as the soil was sufficiently warm and danger of late spring frosts was past. This is about April 20 for the Wenatchee area.

When conditions were correct for tomato planting, the seed germinated quickly and the plants grew rapidly until they reached a height of approximately three inches when there was little visible growth for

about three weeks. During that period the leaves often turned a purplish-green color. While in this condition the tap roots grew rapidly and careful attention was given to watering and general cultivation. Care was used in cultivating to avoid disturbing the root systems of the tomatoes as plants thus disturbed were affected quickly with curly top (blight).

During the period of slow top growth, the tap root penetrated below the more arsenic-toxic surface soil layer and after that stage of development had passed the tops began to grow rapidly.

Thinning excess plants from the row is not absolutely necessary to good plant growth and yield, but it was found that more sturdy plants were obtained if the plants were thinned to stand about 12 inches apart in the row. Removing the excess plants at the ground line with a blunt pair of scissors was the best and least injurious method tried from the standpoint of curly top infections.

While a number of varieties were tested, all appear to have approximately the same degree of tolerance to arsenic toxicity.

The type of plant growth that can be expected when planting tomatoes by the direct-seeding method and thinning the plants to stand 10 to 12 inches apart in the row is shown in Figure 3.

Fig. 3. Tomatoes seeded directly in arsenic-toxic ex-orchard land containing upwards to 33 parts per million of water soluble arsenic.

Carrots. Carrots were quite resistant when grown in arsenic-toxic ex-chard soils of varying texture. When planted in light-textured soils care was taken to have the soil amply moist before seeding or a poor stand of plants resulted due to a washing of the seed when irrigating or by covering them too deeply. Lack of a carrot stand some years in certain sections of the sandier plot resulted from other causes than arsenic toxicity of the soil. Examinations of such plantings showed the seed to be missing or covered so deeply that the delicate plants could not grow to the soil surface.

Red Cored Chantenay, Improved Nantes, Imperator, and Crosby's Egyptian were planted each year of the test with no one variety showing more tolerance of water soluble arsenic than the other. Good yields of marketable carrots were obtained from the first plantings in 1939. The only evidence of arsenic injury to carrots was seen in a slight yellowing or browning of the basal leaves of the plants grown in the sandy soil plot.

Tobacco. Tobacco was added to the plantings in 1942 as a wartime investigation. Fruit growers use rather large quantities of nicotine extract in their spray programs as a control for aphis. Because of the fact that nicotine is used at present in the manufacture of war explosives, investigations were initiated to determine (1) whether tobacco would grow on toxic ex-orchard soils and (2) the nicotine content that could be expected.

Fig. 4. Tobacco plants approximately 4 feet tall, after detasseling, as grown on medium heavy and light sandy arsenic-toxic ex-orchard land.

High-nicotine species of tobacco were obtained and the plants grown in pots to transplanting size in the greenhouses at Pullman. They were then taken to Wenatchee and planted in the toxic soil plots in rows three feet apart by two feet betwen plants in the row.

While only two years data have been obtained, tobacco proved to be very tolerant of water soluble arsenic. In fact, the best all-around

plant development was made in the light sandy soil plot containing the most parts per million of water soluble arsenic. In the heavy clay soil plot, longest out of orchard when planted, the tobacco plants were a foot taller but the stems were more slender and the leaf blades narrower than was the case on medium-heavy and sandy soil plots where the plants were very stocky and the leaves broad. (See Figure 4.)

Nicotine determinations[1] were made on tobacco leaves in 1942 and nicotine content was highest in every case in the rye-manure-nitrogen sections of the plots. In the plot having the heaviest soil and the lowest water soluble arsenic content (Table 1), the tobacco leaves analyzed 2.08 per cent nicotine in the rye-manure-nitrogen section. In the medium heavy soil plot in the same section the tobacco had 2.54 per cent nicotine; and in the sandy soil plot in the same section, the tobacco leaves analyzed 3.80 per cent nicotine. The per cent nicotine might have been higher had the plants been de-branched and detasseled more regularly. Nicotine content of the 1943 crop, the plants of which were pruned at regular intervals, will be determined.

Dewberry. The Boysenberry was the only variety of dewberries included in the toxic plot studies and the plants grew very well and produced good crops of berries each year after coming into bearing, regardless of soil texture or the parts per million of water soluble arsenic in the test plots. The best growth and heaviest yields were obtained in the sandy soil plot, highest in arsenic. Cane growth was much more vigorous in all plots when the one year old berry plants were set in the field following the growing and plowing under of two crops of rye, than when set in the field before rye was grown.

While Boysenberries grow well in arsenic-toxic soils, their growth as a commercial enterprise in the Wenatchee district is questionable. In the first case the plants are not entirely winter hardy and the young canes need some winter protection in order to carry them through the winter uninjured. In the second place the Boysenberry is very susceptible to mosaic infection and 100 per cent of the plants now show serious infection in the plot having the heavy soil, lowest in water soluble arsenic. The third factor of considerable importance is the great care required in handling the young canes.

When the new canes were allowed to grow on the ground or were left on the surface of the soil under the mother plants they become badly entangled during the growing season. In lifting the vines off the ground on to the trellis, the vines had to be pulled apart by force and in so doing some of the prickles were torn off the canes. When too many briers were pulled off, the canes were girdled and as a result the

[1] Nicotine content of the tobacco was determined by Herman Fallscheer, Assistant Chemist, Tree Fruit Branch Experiment Station, Wenatchee, Washingon.

part of the cane above the lowest girdle died. The greatest reduction in yield of fruits was from this type of injury although the Boysenberry canes are subject to winter killing or winter injuury. This could have been prevented by covering the canes with two to three inches of soil, straw or other litter before freezing weather arrivd. By arranging the canes in an orderly fashion in the rows, as they grow, much of the brier injury could have been eliminated.

Red Raspberry. Raspberries grew vigorously from the first year even when planted in heavy soil analyzing upwards to ten parts per million of water soluble arsenic at the time of planting. (See cover page.) However, cane growth was even more vigorous when the berries were planted in portions of the same plot that had been sown to a rye crop for one year previous to planting one-year-old raspberry roots.

On medium heavy and also on sandy soils, having a higher water soluble arsenic content than the heavy soil, raspberry cane growth during the first season (1939) was in relation to the water soluble arsenic content of the soil and to the soil texture. This difference continued through 1943. Growth of raspberry canes was about comparable in the medium heavy soil plot and in the sandy soil plot containing the most water soluble arsenic. Cane growth was more rapid and somewhat more vigorous in these plots following the growing and plowing under of the two rye crops in 1939.

The evidence obtained, since the first plantings of red raspberries in toxic soils in the Wenatchee area in 1939 and 1940, proves that red raspberries will grow and produce good crops of fruit in soils of heavy, medium, and light texture and also containing high, intermediate, and relatively low parts per million of water soluble arsenic. However, the heaviest type of soil, containing the least parts per million of water soluble arsenic, was the most favorable to vigorous plant growth and high fruit yields.

The study also shows a definite difference in varietal tolerance to arsenic toxicity. Four varieties, Washington, Tacoma, Lloyd George, and Cuthbert were planted in each of the toxic plots. Of these, the Washington, a mid-season variety, was by far the most adaptable and tolerant and is recommended for planting in arsenic toxic exorchard land. Tolerance rating of the others is Tahoma, Cuthbert and Lloyd George, respectively. While both the Cuthbert and Lloyd George are commercially important varieties in certain regions of Washington, they are the least hardy of the four when grown in toxic soils. It is possible that other varieties can be found having even greater adaptability (see cover page) than the Washington.

Grapes. Four varieties of grapes were planted in the toxic soil plots, namely Zinfandel, Csaba, Concord and Campbell's Early. The

first two named varieties are European or wine grapes, and the last two are American varieties or dessert grapes. All four varieties grew almost normally in the three types of soils and with the different degrees of arsenic toxicity encountered in the various test plots.. In fact, these grape varieties were very tolerant to water soluble arsenic and made normal plant growth regardless of soil texture.

Yield of grapes was high for all varieties in all sections of each plot but the best all-around growth and yield performance, each year after the plants came into production, was in the section of the plots treated with ammonium phosphate applied at the rate of 48 pounds of available nitrogen and 60 pounds of phosphorus per acre. Leaf size, type of vine growth and fruit set of the Zinfandel variety as grown in toxic ex-orchard soil, when fertilized with ammonium phosphate, is shown in Figure 5. Fruit set and general plant performance is very similar to that pictured when grown under other soil treatments such as with manure, rye-manure-nitrogen, and rye-nitrogen.

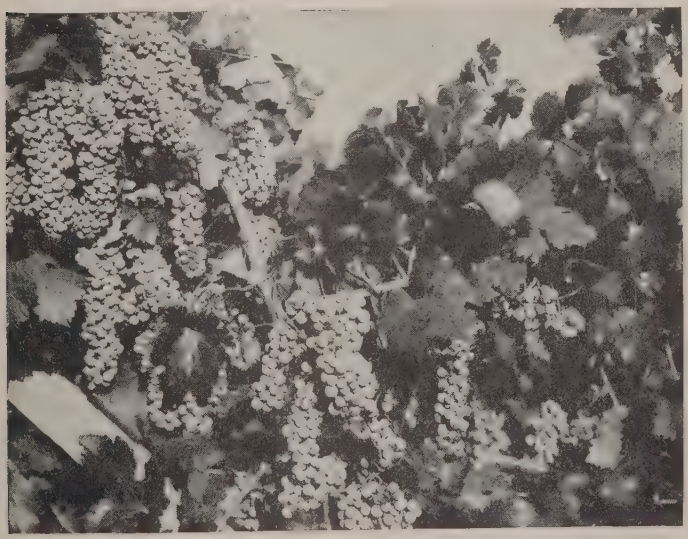

Fig. 5. Showing fruit set and general plant characteristics of the Zinfandel grapes when grown in arsenic toxic ex-orchard soils.

From these studies it is safe to recommend the planting of grapes in arsenic toxic soils, even those soils of a sandy nature high in water soluble arsenic.

The grape varieties planted in the test plots are not necessarily recommended as being the vest varieties for commercial plantings. In fact, while Zinfandel is being planted as a wine grape in the Wenatchee area, it was found that two out of three Zinfandel plants in the test plantings were badly infected with crown gall disease following two years of growth in the field. It is a well known fact that most European grapes are very subject to winter injury, winter killing or both. While there has been no real test year against cold since establishing the plots, the winter weather of 1942-43 was sufficiently low to do considerable winter injury to the canes of both Zinfandel and Csaba varieties. These varieties were affected with winter injury in all plots and shoot growth was delayed approximately 14 days beyond normal in 1943 because of low temperatures during the winter of 1942-1943. In a few instances, especially with the largest canes, winter injury was so severe that some canes did not survive and were pruned out in the spring of 1943.

In the Wenatchee district, Csaba was found to ripen its fruits in late August, Campball's Early in mid-September, Concord in late September and Zinfandel in early October.

KINDS OF VEGETABLES AND SMALL FRUITS FAIRLY TOLERANT TO ARSENIC

Beets and squash were found to be fairly reliable vegetables to plant in arsenic toxic soils whether the soil is low or high in water soluble arsenic or whether the soil texture is heavy, medium heavy or of a light sandy nature.

The best growth was obtained in those sections of the plots following the growing and plowing under of rye as a green-manure crop. In the sections of the plots to which 16 tons of cow manure had been added each year since the inception of the investigations, these crops grew well after the manure had become thoroughly incorporated and had become an integral part of the soil.

Beets. Lack of high arsenic tolerance in beets was evidenced by the yellowing and dying of the lowest and oldest leaves on the plants. This does not become serious, however, until after the roots have reached the edible stage. This was more evident with beets grown in the lighter soils of high water soluble arsenic content than in the heavier soils containing lesser amounts of water soluble arsenic. Of the three beet varieties planted, Detroit Dark Red, Crosby's Egyptian and Early Wonder, none appeared to possess greater tolerance than the other.

Squash. Both Marblehead and Table Queen varieties of squash were planted in the toxic plots and each seemed to possess a comparable

degree of arsenic tolerance. Vine growth was satisfactory in all sections of each plot, but the greatest vine length and leaf size were found each year in those sections of the plot treated either with cow manure alone or with rye-cow manure-nitrogen additions together. In all cases the least plant growth was made in those sections treated with ammonium phosphate.

The vines of the squashes blossomed profusely but the set of fruit was rather light, indicating that the set might be influenced by the arsenic content of the soil. This deduction is supported by yields of squashes produced in each of the three plots. The highest yields each year were obtained on the plots found to contain the lesser parts per million of water soluble arsenic.

Sweet Corn. Sweet corn was a fairly dependable crop to plant in toxic soils of heavy or medium heavy texture following the growing and plowing under of the rye crops. On light sandy soils high in water soluble arsenic, sweet corn failed to grow past the seedling stage in any section of this plot.

Corn, when planted in those sections of the heavier soil plot that had been out of orchard six years before being cultivated, and when planted in those sections of the medium heavy soils that had had two or more crops of rye plowed under before being planted to corn, made "good growth" and "fair plant growth" respectively in the rye-manure-nitrogen, and in the rye-nitrogen sections as shown in Figures 6A and 6B.

A B C

Fig. 6. Golden Cross Bantam sweet corn growing in heavy texture arsenic-toxic soil, (A) the second year of treatment and (B and C) the same variety planted in medium heavy arsenic toxic soil the second year of treatment.

On the heavy soil lowest in water soluble arsenic, at the time of laying out the plots, corn grew unevenly in 1939, the first year of seed-

ing. At that time only two sections were planted to corn, one of which was treated with ammonium phosphate and the other cow manure. The remaining two sections were planted to rye and were not seeded to corn until 1940. In 1939 the corn stand was uneven, the stalks spindling and the corn yield low. The leaves of the plants in each section were a yellowish green in color and the lower leaves turned brown and died by mid-summer. In 1940 the stand of corn on the two sections, which had grown a spring and a fall rye crop previous to planting, was very uniform throughout the two sections (Fig. 6A) and the leaves were normal in size and a dark green color. The two sections previously planted to corn in 1939 responded similarly in 1940. It was not until 1942 that all sections of this plot became fairly comparable in plant stand, leaf size, color, and yield. The corn in the two rye sections maintained a slight growth advantage over the manured section during 1942 and 1943 and a decided advantage over the corn plants in the section treated with ammonium phosphate in 1942 and 1943.

On the medium heavy soil (Figure 6B), corn was a complete failure in 1939 on the section treated with ammonium phosphate and on the section treated with cow manure. Only a few plants grew in the interspaces between the spots where the old trees formerly stood, and the corn plants that did grow only reached a height of 2½ to three feet. From the beginning the leaves were yellowish in color and the plants died by mid-summer without producing ears.

In 1940, corn planted in the sections sown to rye during the spring and fall of 1939 made fairly good plant growth (Fig. 6B) although the corn leaves lacked the good green color generally characteristic of corn grown in non-toxic soil. Also the lower leaves of the plants grown in these sections turned yellow and later died, an index of arsenic poisoning in corn when otherwise properly grown.

The sections treated with ammonium phosphate and with cow manure were planted to corn again in 1940 but the stand was very uneven and the plants weak in the first mentioned section while those in the section treated with cow manure were somewhat better. (Fig. 6C). By 1943 the stands were improved in each of these two sections over the previous years stand, but in no case was the general plant response comparable to the sections planted to two crops of rye in 1939 and a fall crop of rye each following year.

In light sandy soils, high in water soluble arsenic, regardless of the treatments given the plot each year, sweet corn seldom survived the seedling stages. The seed would germinate but the young seedlings did not live after the food supply of the seed had become exhausted. Examinations of the tap roots of dying seedlings showed that the epidermis had turned black, evidently from the action of water soluble arsenic. A few plants here and there in the various sections did reach ma-

turity but the plants were weak and non-productive. The best stand of plants in this plot was obtained in 1943 but it was very unsatisfactory.

Several sweet corn varieties were planted in each of the three plots during these trials but Golden Cross Bantam was by far the most tolerant to arsenic of the varieties tested. Limited trials with field corn did indicate that it was more tolerant of arsenic, even in very toxic, sandy soils, than was any sweet corn variety planted to date. Observations of farmer plantings in the Wenatchee district also support the deductions that field corn is more tolerant of arsenic than sweet corn especially when planted in heavier ex-orchard soils containing low to medium parts per million of water soluble arsenic.

Strawberries. Four varieties of strawberries, Red Heart, Premier, Dorsett, and Fairfax, were planted in 1939 in the ammonium phosphate and in the cow manure sections of each of the three experimental plots. In 1940 the same varieties were planted in the remaining two sections of each plot previously planted to two rye crops in 1939.

Growth with all varieties was apparently normal during 1939 in the heavy textured soil plot, the varieties responding equally well in each of the two sections. In the medium heavy soil, Fairfax grew normally exhibiting highly tolerant properties to arsenic, with Red Heart and Premier showing considerable tolerance. Dorsett was very susceptible to arsenic toxicity and all plants died soon after planting. In the case of the sandy plot plants of the four varieties died within a few weeks of planting in 1939.

In 1940, the four varieties were planted in the two sections of each of the three plots planted to rye in 1939. In the heavy soils the young plants of all four varieties grew vigorously and made an even greater annual plant growth than was made by the same varieties in 1939 in the other two sections of the same plot. In the medium heavy soils comparable results were encountered to those indicated for 1939, but in this case the tolerant Fairfax variety made a more vigorous plant development in the rye sections than was made in 1939 in sections (a) and (b).

None of the varieties grew in any section in the sandy soil plot when planted as late as the spring of 1943 after five consecutively yearly treatments.

From the studies made, a varietal tolerance is strongly indicated among strawberry varieties although this is definitely related to soil texture and parts per million of water soluble arsenic in the soil. As the parts per million of water soluble arsenic increases in sandy and medium heavy soils, strawberries do not appear to be a safe crop to plant.

VEGETABLE AND SMALL FRUIT KINDS LOW IN TOLERANCE OF ARSENIC

Some kinds of vegetables as snap beans, Lima beans, peas, onions, and cucumbers appear to have little or no tolerance of water coluble arsenic when grown in ex-orchard soils. Sweet corn and strawberries also show low tolerance when planted in light sandy, ex-orchard soils.

Snap beans, Lima beans, and peas. Legumes generally show little or no tolerance to soluble arsenic. When first planted in 1939, beans and peas in sections (a) and (b) of all plots died soon after emerging from the soil. Similar results were obtained through the 1942 season in the medium heavy and sandy soil plots regardless of the soil treatment. In 1943 peas made a slight plant growth and produced a very light crop of pods in all sections, in the medium heavy soil plot. Beans died in all four sections of this plot soon after emerging as in previous years. In the sandy soil plot both peas and beans died soon after emergence from the soil from 1939 to 1943 inclusive.

In the heavy soil plot, snap beans and peas germinated and grew fairly well in 1940 in the two sections planted to rye in 1939. In sections treated with ammonium phosphate and cow manure, peas and beans died in 1940 after making a slight growth.

From 1941 to 1943, beans grew almost normally in the two rye-treated sections of the heavy soil plot, but in sections (a) and (b), plant growth was slightly less vigorous. The heaviest yields were obtained in this section from 1941 on, but in 1943 beans in the sections treated with manure were almost as productive. Pea plants did not show complete normality in sections (a) and (b) as late as 1943, although the plant development and yields from 1941 through 1943 were very satisfactory in the rye-manure-nitrogen section, followed closely by the pea growth and yields in the manured section. Lima beans proved to be the most susceptible to arsenic injury and in no year lived through the seedling stages.

This work clearly indicates that beans and peas are not safe crops to plant in ex-orchard lands until after several crops of rye have been grown and plowed under as green-manure crops or until two or more yearly applications of barnyard manure have been made and the manure allowed to become well decomposed and incorporated as a part of the soil. On light textured soils yearly plantings of beans and peas resulted in complete failure regardless of the soil treatments made. While several varieties of beans and peas were planted, no difference in arsenic tolerance was detected.

Onions. Onions seeded in 1939 and in 1940 failed to live through the seedling stages regardless of soil texture and soil treatments. After

1940, onions were not included in the plantings, so it is possible that growth would have improved as the soil treatments continued.

Sweet Corn. This crop, as indicated previously, did not grow past the early seedling stage in the light sandy soil plot regardless of treatment. A few sweet corn plants grew in 1943 in each section of the sandy soil plot, but the plants were very weak and no ears were harvested. Field corn plantings, made in this plot, resulted in almost complete failure. In this case, also, the best stand was obtained in 1943, but none of the treatments seemed to be superior to the others.

Strawberries. Strawberry plantings made in the light sandy soil plot did not survive transplanting. Fall and spring plantings made in 1941 and 1942 resulted in death of the plants. Since strawberries have a small root system, compared with other small fruits tested, it is concluded that death of the plants was due to the roots being planted in the more toxic soil near the surface.

DISCUSSION

Rye was found to be very resistant to water soluble arsenic and is now grown extensively in the Wenatchee district as both a cover crop in old orchards and as a green-manure crop in reclaiming ex-orchard soils high in water soluble arsenic. It is highly recommended that all ex-orchard lands be planted to two or more crops of rye before attempting to grow most vegetables and small fruits. Because of its extensive root system, top growth, and tolerance to arsenic, rye is one of the best soil improving crops known. However, according to investigations conducted in Idaho with ex-orchard lands, Verner and Woodbury (6) found Sudan grass to be an excellent cover crop for reclaiming arsenic-contaminated soils after apple trees have been removed. They state "Should the land not be in suitable condition for the first seeding of a cover crop until late spring, Sudan grass should be sown first rather than rye. This crop may be planted any time after danger of frost is past. Winter rye should follow in early autumn."

Land from which old apple trees have been removed should be plowed, harrowed and leveled as soon as possible after the trees are pulled. Many tree roots will remain in the soil following tree removal. A large plow may be required to loosen the larger roots. A Fresno is a good implement to fill in the depressions where the trees stood. If the soil can be prepared for early spring seeding, the land should be seeded to spring rye at once using 80 to 100 pounds of seed per acre. If necessary, the soil should be irrigated before seeding to allow rapid germination of the seed. After the rye is through the ground, the plants should be irrigated often enough to insure rapid growth. The crop should be allowed to grow until it is in the early bloom stage when

250 pounds per acre of ammonium sulphate or some like fertilizer should be braodcast over the rye before plowing it under. The nitrogen applied will aid in the rapid decomposition of the rye providing the soil is kept amply moist.

The spring crop of rye should be given ample time to decompose following plowing. In late August or early September, the field should be worked to a fine state of tilth by disking and cultivating. Rosen rye should then be planted at the rates previously mentioned and the plants allowed to grow through the fall and winter until time to plow the stand under the next spring. The rye should be irrigated following seeding to obtain a good stand. It is recommended that the fall planted crop also be permitted to reach the bloom stage before being plowed under although this will probably be determined by the needs for the soil by the individual. The more rye crops that can be grown in arsenic-contaminated soils the greater are the probabilities for success in the growing of vegetables and small fruits except for those crops tolerant of water soluble arsenic. Following the plowing under of any green-manure crop, decomposition will be hastened by the application of some nitrogen carrying fertilizer.

Unless the arsenic properties of the soil have been reduced to a point where arsenic is no longer toxic to plants, approximately two parts per million, it is useless to attempt to grow vegetables or small fruits of low arsenic resistance. (See Table 2.) It may require growing rye for as long as four or five years before this point is reached in the case of sandy soils, containing upwards to 20 to 30 parts per million of water soluble arsenic at the time of tree removal.

Seeding ex-orchard lands to green-manure crops for a period of years may seem a costly and slow process for reclaiming lands, yet it must be recognized that any program of refitting such soils will of necessity be expensive if high yielding money crops of all kinds of vegetables or small fruits are to be grown.

When Rosen rye was planted between the rows of small fruits each fall and in certain sections of the vegetable plots, the arsenic content of the soil was not only lowered but the addition of organic matter greatly improved the texture of the soil. Increasing the organic matter content of the soil also greatly aided in the lateral spread and penetration in the soil of the irrigation water.

Barnyard manure can be used with beneficial results in reclaiming ex-orchard land but should supplement rather than substitute for rye as a soil-building material. Barnyard manure is not immediately beneficial to the growing crop until after it has been thoroughly broken down and become a part of the soil. This is particularly true if arsenic-contaminated soils are to be planted without having previously

been seeded to rye or some other arsenic tolerant green-manure crop. There is some evidence that volunteer weeds may be used for reclaiming ex-orchard soils but the most economical program is one that will return the land to profitable production in the shortest time possible.

SUMMARY

In the tree fruit districts of central Washington, there are some 12,000 to 15,000 acres of ex-orchard lands lying idle. Some of this land is not satisfactory for replanting to orchard but most of it might be used for the production of vegetables and small fruits.

Because of heavy sprays of lead arsenate applied to apple trees over a period of 30 to 40 years, an arsenic-toxic soil complex has developed from the accumulation of water soluble arsenic in the top five or six inches of the soil, making the growing of most crops unsatisfactory.

Investigations conducted by the Washington Agricultural Experiment Station, Division of Horticulture, shows that a few kinds of vegetables and small fruits can be grown successfully in arsenic toxic soils regardless of their soil texture and parts per million of water soluble arsenic. It was also found that the growing of rye green-manure crops, applications of manure or combinations of manure and green-manure crops will reduce the parts per million of water soluble arsenic in soils to such a degree that some of the less tolerant vegetable and small fruit crops will grow successfully following a few years of soil treatment.

Three plots, each one-half acre in size, were laid out in the Wenatchee area in the spring of 1939 to study the effects of arsenic toxicity on the growth and development of crops and to study ways and means of eliminating the trouble. Plots were selected (1) on the basis of interval after old apple trees were removed; (2) on soil texture; and (3) on the arsenic content of the soil. Each plot was divided into four equal areas. Area (a) received yearly applications of ammonium phosphate; area (b), yearly applications of cow manure; area (c) was seeded to a spring and fall crop of rye the first year, and a fall crop of rye thereafter. Area (c) also received amounts of cow manure comparable to area (b) and received 50 pounds of actual nitrogen (acre basis) before plowing under the rye. Area (d) was handled yearly as area (c) except that the manure was omitted.

Tolerance of a few crops to arsenic has been determined. The most tolerant crops of those studied to date are asparagus, Irish potato, tomato, carrot, tobacco, dewberry, grape, and red raspberry. While these crops can be grown with considerable success in toxic ex-orchard soils, plant response and yields were somewhat increased when they

were planted following the growing and plowing under of two or more crops of rye as soil improving crops.

Certain vegetables and small fruits were found to possess some tolerance to water soluble arsenic especially when planted in heavy texture and medium heavy texture soils. They are sweet corn, beets, summer and winter squash, and strawberries.

Crops found to have low tolerance or none at all to water soluble arsenic are snap beans, Lima beans, onions, peas, and cucumbers. Sweet corn and strawberries show no resistance to arsenic when planted in light sandy soil but show considerable tolerance when planted in heavier soils.

The growing of rye as a soil improvement crop aided greatly in reducing the parts per million of water soluble arsenic in the soil. Both tolerant and semi-tolerant crops grew more normally following rye than when the same crops were planted in sections not including rye as a part of the treatment.

Cow manure was found to be beneficial in reducing the parts per million of water soluble arsenic in the soil but plant growth was not greatly benefiited by the manure until the third year of planting, and following the thorough decomposition and incorporation of the manure as a part of the soil.

Applications of ammonium phosphate, in the amounts used, also reduced the parts per million of water soluble arsenic, but plant response generally was not as good in this section of each plot, as in the other sections, throughout the years of the study. This poor plant response was assumed to be due to a lack of organic matter in the soil causing the water soluble arsenic to be more toxic to plant roots than would have been the case had organic matter been present. The growing and plowing under of rye green-manure crops appears to be much more active than commercial fertilizers used alone in making residual arsenic less injurious to plants.

There appears to be some varietal tolerance in the case of some kinds of vegetables and small fruits to water soluble arsenic. Golden Cross Bantam sweet corn possessed more tolerance of arsenic than other varieties planted; Washington variety of red raspberries and the Fairfax variety of strawberries showed more tolerance than other varieties planted. More study is needed on varietal tolerance to arsenic.

Crops planted in clay and clay loam soils were less affected by water soluble arsenic than crops grown in medium heavy and light sandy soils. Crops grown in sandy soils showed, as a rule, the least tolerance to arsenic of any of the three types of soil, included in the study, probably due to its low organic matter content.

The possible explanation, other than natural tolerance, of the good results with grapes, red raspberries, and dewberries, when planted in toxic soils, as compared with strawberries, is that the roots of such plants are placed below the most toxic layer of soil when planted.

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